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The risk of low-back disorders (LBD) may be particularly great for women in the military, influencing training effectiveness, costs and military readiness. The goal of this research is to quantify musculoskeletal loads on the spine of women performing military manual materials handling (MMH) tasks. This will permit assessment of LBD risk factors for military women, and the potential to evaluate tasks and training methods for female military personnel.

Our efforts are progressing in general accordance with the proposal and timeline. Magnetic Resonance Images (MRI) have been employed to measure muscle cross-sectional areas, lateral and anterior-posterior moment arm distances in healthy women. To date, we have collected and analyzed a majority of the imaging data. Force-length and force-velocity relationships must be quantified to describe the physiological dynamics of MMH tasks. Equipment and methods for these measurements have been calibrated and tested on a male population. These techniques will be employed on a female population once a complete data set is achieved from the MRI study.

After the first year of this research effort, we are progressing well and confident that an accurate biomechanical model can be developed for the evaluation of spinal load of women performing military MMH tasks.

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FOREWORD

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William J. Moore 10/18/96

PI - Signature Date

EXECUTIVE SUMMARY

Low back injuries in female military personnel can significantly impact training effectiveness, costs and military readiness. Low back injuries represented 75% of compensable military injuries in 1988 through 1991 (1). When one considers that women have significantly higher incidence of lost time injuries during basic training than men (2), it is apparent that the risk of work related LBD may be particularly great for women in the military. Heavy manual materials handling (MMH) that would challenge the injury tolerance of most industrial workers' spines has been shown to be the most physically demanding task in 90% of all military job specialties (4). As these MOSs are becoming increasingly available to women, the risk LBD to women will have greater consequences as they fill these roles, particularly when considering a downsizing military. Thus, there is a need to reliably assess the risk of military task related LBD to women, and to identify potential features or training that might mitigate that risk.

The goal of this research is to extend the capability of predicting musculoskeletal loads on the trunk and spine to women performing realistic MMH tasks. Current models of musculoskeletal loading on the spine are based upon male biomechanics, and must be enhanced to account for the anatomical geometry and physiology of the female musculoskeletal torso. This will permit accurate evaluation of the spinal loads in women as they perform military MMH activities, and the potential to assess the relative risk of female military personnel performing MMH tasks in comparison to male personnel.

The first two phases of this effort have begun and are designed to describe the biomechanical geometry and physiology of the female musculoskeletal torso. First Magnetic Resonance Imaging (MRI) techniques have been employed to quantitatively describe the internal geometry of the female trunk musculoskeletal system so that the model can accurately represent internal trunk mechanics. Second the evaluation of force-velocity and length-strength relationships that are unique to the female trunk musculature and physiology are underway.

Our efforts in this research is progressing in accordance with the proposed timeline and as we expected. To date, we have collected a majority of the imaging data on the healthy women, and have analyzed over half of it. We have managed to expand this phase of the research, to allow assessment of healthy subjects for improved validity and to collect data of healthy males for direct comparison. The results agree with the existing literature, indicating the methods, data, and processing we have been using will lead to valid mechanical representations of the torso.

The equipment and methods to be for the determination of the force-length and force-velocity relationships have been calibrated and tested on a male population. Furthermore, the methods and associated validity of the results have been expanded to include representations of eccentric muscle contractions. Once a complete data set is achieved from the MRI study, we are confident the description of the force-length and force-velocity relationships will continue without difficulty.

After the first year of this research effort, we remain confident that we will successfully develop an accurate biomechanical model for the evaluation of spinal load of women performing MMH tasks. These results may permit assessment of work related LBD, and identification of methods and training techniques that will reduce the risk of low back injury in female military personnel.

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INTRODUCTION

The control of women's Low-Back Disorder (LBD) risk should be a priority for the military to mitigate escalating injuries, costs and to maintain military readiness and combat effectiveness. Low back injuries represented 75% of compensable military injuries and have cost the Army between 46.9 and 61 million dollars per year in 1988 through 1991 (1). When one considers that women have significantly higher incidence of lost time injuries during basic training than men (2), it is apparent that the risk of work related LBD may be particularly great for women in the military. The cost of LBD risk among military women extends beyond medical care expenditures and long term or permanent compensation for the soldier. There is a great cost associated with lost duty time, training and retraining replacement personnel if a soldier must be discharged because of a LBD. Furthermore, military effectiveness and readiness are compromised if the soldier is not able to perform peacetime or combat related tasks because of a LBD.

Many of the military occupational specialties (MOSs) have recently been made available to military women (3). As of 1995 there were women filling roles as combat engineers, in field artillery, and land combat MOSs. The number of women in these combat related MOSs is expected to increase. As women fill an expanded role in the modern military, the risk of lost female personnel due to LBD will have greater consequences upon military readiness and combat effectiveness than ever before. With military downsizing, the importance of each military women, and the repercussions of LBD will become critical.

Many of the MOSs now being filled by women requires heavy manual materials handling and would be expected to challenge the tolerance of most industrial workers' spines. Sharp and Vogel (4) have shown that "heavy MMH is the most physically demanding task in 90% of all military job specialties." Yet these activities have never been quantitatively evaluated with military women. Thus, there is a need for a model that can accurately and reliably assess and evaluate the risk of LBD to women as well as what features or training might mitigate that risk.

The Ohio State University EMG-assisted biodynamic model can be developed to provide a tool to assess and evaluate the risk of LBD to women performing military MMH tasks as part of their

MOSs. Our previous efforts have demonstrated that we have been able to build a three-dimensional model of the trunk that is capable of accurately assessing spine loads during free-dynamic trunk motion which accounts for muscle co-contraction (5,6,7,8). However, the modeling efforts to date have been successful in modeling the trunk geometry and subsequent loading imposed upon the spine of only males performing manual materials handling activities.

The geometry of the female trunk is vastly different from that of the male. Women tend to possess greater hip breadth and narrower abdominal depth than men (9). The sacroiliac joint is positioned several centimeters anteriorly in the female changing the moment arm associated with the external load as well as affecting the internal moment arm distances between the muscles and the point of rotation of the spine (10). In addition, muscle attachments are signifcantly different between males and females. These changes will dramatically affect the force-length and force-velocity relationships that are vital for the determination of muscle force (equation 1). In addition, one must understand the differences in the muscle lines of action (attachments) so that the trunk mechanics representation accurately reflects loading of the female trunk.

The ultimate goal of this research is to extend the capability of predicting musculoskeletal loads to women performing realistic MMH tasks. This model will be employed to assess the relative risk for musculoskeletal injury due to a MMH task for women relative to men, and to evaluate the proposed changes to those tasks to quantify the change in LBD risk. This EMG-driven model will then be available as a tool to assess the risk associated with specific MMH tasks performed as part of MOSs that have recently been made available to military women. In this manner it will be possible to: a) assess risk for a given task, b) evaluate the physical attributes of a potential recruit that would place her at an increased risk of LBD, and c) determine how training or workplace procedures might be changed to minimize risk of LBDs to women (and men) performing the military MMH task.

In order to accomplish these objectives, it will be necessary to accomplish five specific aims. 1.) Quantitatively describe the internal geometry of the female trunk musculoskeletal system so that the model can accurately represent internal trunk mechanics and lines of muscle action. Magnetic Resonance Imaging (MRI) will be used to collect this information is a safe and accurate manner. 2.)

Determine the force-velocity relationship and length-strength relationships that are unique to the female trunk musculature. 3.) Implement female trunk geometry and muscle relationships into the existing OSU EMG-assisted biomechanical model. 4.) Test and validate the model under laboratory conditions. 5.) Use model to evaluate military MMH tasks of physically demanding MOSs performed by both males and females.

The purpose of this document is to report on the progress made in the proposed research over the first year of activity. Specifically, the quantification of the musculoskeletal anthropomentry of the female torso by MRI analyses, i.e. part 1; and the initial stages of the description of force-velocity and length strength relationships of female musculoskeletal behavior, Part 2 of the research shall be discussed

PART 1 : Anthropometric MRI measurement of female musculoskeletal torso

BACKGROUND AND OBJECTIVES

The objective of Part 1 was to generate descriptive statistics to describe the relative anthropometric values of muscle cross-sectional areas, origins, and lines of action in the female torso. The model currently accepts regression equations to predict muscle anthropometry of male subjects (5,6,7,8). This is critical for scaling modeled muscle force amplitudes, dynamic behavior and to predict musculoskeletal loads. In order to generate accurate assessments of spinal loading and associated LBD risk of females performing military MMH tasks, it is necessary to generate a biomechanical geometry that accurately describes military age women. Although measures of soft tissue have been reported on elderly females (11,12), there have been no studies designed to measure the trunk muscle area and geometry of young active women.

ADMINISTRATIVE NOTE

In the accepted research proposal, the "Statement of Work Addendum" included the collection of anthropometric data describing relative trunk muscle sizes and biomechanical lines of action on 20 women from existing MRI scans. Thus, we were to find torso imaging data of women who had required medical diagnososis of disabilities. The originally proposed "Statement of Work" suggested MRI analyses be performed by scanning 20 healthy women. However, due to budget limitations imposed by USARMC prior to approving the research, it was necessary to revise this part of the research to meet the financial constraints with the "Statement of Work Addendum" as described above.

We have managed to supplement the experimental design of the MRI with alternative funding that will improve the validity and specificity of the research for the purposes of the research goals and objectives. This was achieved by finding the opportunity to support data collection of healthy military age women, a population which more realistically represents active military women. A local hospital with a state of the art MRI facility has agreed to participate in this effort, allowing us the opportunity to scan 20 healthy women and 6 healthy men. This will improve the validity of the data by providing MRI scans of healthy women instead of scans from disabled women, avoiding confounding musculoskeletal factors.

The alternative funding opportunity has also allowed us to collect data for direct comparison of male versus female relative muscle areas, attachment points, and lines of action. To date, there have been no such published analyses of muscular mechanical geometry. The final column in tables 2 through 45 illustrates the average male is represented by larger muscle cross-sectional areas, lateral and AP moment arm distances in terms of un-normalized magnitudes. Further analyses will examine the relative differences after normalizing for body size, i.e. trunk depth and width. This data will allow a direct comparison of the biomechanical loads generated by female versus male soldiers during MMH lifting activities. The comparison will permit a more valid assessment of LBD risk of women as compared to men, and the influence of task design upon gender related LBD risk.

METHODS

Experimental Design : Female subjects are currently being placed in the Magnetic Resonance Imaging (MRI) chamber at Riverside Methodist Hospital, Columbus, OH. where cross-sectional images of the trunk are collected. The scanner (Philips GyroScan) was set to a spin echo sequence of TR=240 and TE=12, generating slices of 10 mm thick. Subjects lie in a neutral position defined as a supine posture with knees extended and hands lying on their abdomen, on the MRI gantry. The gantry moves the subjects into the center bore of the MRI magnet, aligning the subjects such that scans can be performed on the desired region of the torso. A single set of 11 torso musculature scans is achieved perpendicular to the gantry table at transverse levels through approximate centers of the vertebral bodies in the lumbar and thoracic regions of the spine. This includes transverse scans of the torso through S1, L5, L4, L3, L2, L1, T12, T11, T10, T9, and T8. A sagittal scout view is also collected to permit vertical quantification of individual transverse planes from the cross-section scans.

Subjects : Female subjects of military age are recruited from a the local community. The target heights and weights were compared to specific groupings (Table 1) to represent the anthropometric variability of women in the military (13). To date, we have collected MRI data on 15 women, with the intention of scanning a total of 20. In order to directly compare the results with relative male anthropometry, we have collected MRI data on four military age men, with the intention of scanning a total of six. This sample size represents a larger experimental design than previously published studies of male anthropometry (14,15). The variability of these measures are significantly reduced and associated statistical power enhanced by scaling the relative to each individuals trunk depth and breadth.

Table 1. Classification of Subject Characteristics

Group #	Height (Percentile)	Weight (Percentile)
1	> 75	> 75
2	> 75	< 25
3	> 25 & < 75	> 25 & < 75
4	< 25	> 75
5	< 25	< 25

Analyses : MRI data are transferred onto a computer (Philips GyroView), where muscle cross-sectional areas can be estimated, and muscle centriods located relative to the spinal disc centroid for each MRI image (15,45). The software permits the user to employ a computer mouse control to encircle the object of interest, then provides statistical data including the area of the enclosed region and three-dimensional location of the area centriods relative to the scan set origin. In this manner, each of 14 muscles are identified, outlined, and quantified at all 11 scan levels. The quantified muscles include the right and left pairs of the erector spinae group, quadratus lumborum, latissimus dorsi, internal obliques, external obliques, rectus abdomini, and psoas major. The sizes and area centriods are also quantified for the vertebral body and the torso mass. Depth and breadth are determined from the MRI scans as well as from direct measurement using anthropometer calipers for comparison.

Each set of scans is analyzed on three separate occasions. The average results are compiled into a muscle by level analysis allowing the computation of the three dimensional muscle vector directions, i.e. lines of action. As a benchmark, results are compared with data from Chaffin et al (11) who examined elderly women, and McGill et al (15) who examined males. Unfortunately, neither the McGill et al (15) data nor the Chaffin et al (11) data realistically represent the biomechanical anthropometry of active, military aged women. Consequently, the objective of this part of the research is to document the musculoskeletal geometry, size, and lines of action of military aged women.

Descriptive statistics shall be developed via regression equations to predict muscle areas and locations from measured values of trunk depth and breadth. Measures of accuracy shall be recorded by documenting the population variability measured between the predicted values and MRI data.

RESULTS

As of mid-October 1996, we have collected MRI scans on 15 of the 20 female volunteers. The imaging data has been analyzed, i.e. identified, outlined, and quantified at all 11 scan levels, on 11 of the 15 complete data sets. Four male volunteers have also been scanned and the data analyzed. The male data set will be used for relative comparison of muscle attachments, lines of action and normalized muscle areas. We expect the complete data set will be collected and analyzed by the beginning of January, 1997, in accordance with the proposed timeline.

Tables 2 through 17 document the data representing the muscle cross sectional areas for each of the 14 measured trunk muscles, the vertebral bodies and the trunk. Also included in those tables are comparative data from Chaffin et al (11) and McGill et al (15) as well as difference values (and percent differences) from those published values. The values in tables 2 through 17 indicate our data generally agrees with published values in terms of the limits of population variances and collection methods. It should be noted that our data set is the first comprehensive description of female anthropometry documenting musculoskeletal geometry from vertebral levels S1 through T8.

A column describing the measured differences (and percent differences) between the average female muscle area cross-sections and male muscle areas has also been provided in tables 2 through 17. These data represent the principal interest for this part of the research effort. Thus, a direct comparison of the male versus female musculoskeletal force generating capacity is provided. However, it must be noted that the data in the tables has not yet been scaled for subject size

Tables 18 through 31 describe the anterior (positive) and posterior (negative) component of the biomechanical muscular moment arm at each level and for each muscle. Data from Chaffin et al (11) and McGill et al (15) are also included for comparison. The values represent the anterior-posterior (AP) distances from the center of the spine. Thus the mechanical advantage of each muscle about the assumed center of spinal motion are described and compared for male and female subjects.

Tables 32 through 45 describe the left (positive) and right (negative) lateral component of the biomechanical muscular moment arm at each level and for each muscle. Data from Chaffin et al (11) and McGill et al (15) are also included for comparison. The values represent lateral distances from the center of the spine. Thus the mechanical advantage of each muscle about the assumed center of spinal motion are described and compared for male and female subjects.

Table 2. Trunk muscle cross sectional area and standard deviations () of the Right Latissimus Dorsi. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Latissimus Dorsi - Cross-Sectional Area

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8	2252 (235)	1581 (159)	671 [42]	1273 (236)			979 [-43]
T9	1942 (125)	1458 (269)	484 [33]	1076 (194)			866 [-45]
T10	1630 (160)	1368 (330)	262 [19]	883 (153)			747 [-46]
T11	1387 (163)	1254 (281)	133 [11]	748 (140)			639 [-46]
T12	1156 (135)	1014 (264)	142 [14]	648 (139)			508 [-44]
L1	935 (95)	717 (260)	218 [30]	467 (87)			469 [-50]
L2	650 (155)	429 (202)	221 [52]	333 (84)	120 (40)	213 [178]	317 [-49]
L3	353 (128)	232 (192)	121 [52]	156 (75)	130 (40)	26 [20]	197 [-56]
L4	117	-			130 (50)		
L5							
S1							

^{A} = Square mm
^{B} = Male minus Female (Square mm)

Table 3. Trunk muscle cross sectional area and standard deviations () of the Left Latissimus Dorsi. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Latissimus Dorsi - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	2247 (101)	1582 (281)	665 [42]	1190 (227)			1057 [-47]
T9	1962 (65)	1417 (293)	545 [38]	1019 (9196)			943 [-48]
T10	1576 (184)	1239 (257)	337 [27]	843 (138)			733 [-47]
T11	1429 (96)	1102 (316)	327 [30]	722 (145)			707 [-49]
T12	1123 (78)	960 (310)	163 [17]	619 (127)			503 [-45]
L1	987 (100)	682 (260)	305 [45]	485 (110)			502 [-51]
L2	727 (137)	372 (161)	355 [95]	344 (72)	140 (60)	204 [146]	382 [-53]
L3	372 (88)	256 (217)	116 [45]	170 (56)	130 (50)	40 [31]	202 [-54]
L4	140		140		150 (60)		
L5							
S1							

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 4. Trunk muscle cross sectional area and standard deviations () of the Right Erector Spinae. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Erector Spinae - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	1383 (173)	1049 (201)	334 [32]	772 (138)			611 [-44]
T9	1455 (126)	1413 (304)	42 [3]	820 (165)			635 [-44]
T10	1631 (147)	1690 (210)	59 [-4]	928 (126)			702 [-43]
T11	1746 (109)	1832 (282)	86 [-5]	1036 (167)			710 [-41]
T12	1994 (312)	2614 (584)	620 [-24]	1060 (146)			934 [-47]
L1	2206 (394)	2615 (405)	409 [-16]	1255 (194)			951 [-43]
L2	2595 (430)	2854 (547)	259 [-9]	1514 (176)	1820 (270)	306 [-17]	1081 [-42]
L3	2684 (259)	2831 (458)	147 [-5]	1635 (206)	1850 (300)	215 [-12]	1049 [-39]
L4	2520 (413)	2151 (539)	369 [17]	1550 (216)	1740 (300)	190 [-11]	970 [-38]
L5	1462 (337)	905 (331)	557 [62]	1076 (435)			385 [-26]
S1	737 (129)			581 (121)			156 [-21]

A = Square mm
B = Male minus Female (Square mm)

Table 5. Trunk muscle cross sectional area and standard deviations () of the Left Erector Spinae. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Erector Spinae - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female [B] [% Diff.]
T8	1436 (198)	1129 (100)	307 [27]	779 (141)			657 [-46]
T9	1487 (45)	1471 (351)	16 [1]	811 (172)			676 [-45]
T10	1699 (77)	1722 (279)	23 [-1]	928 (156)			771 [-45]
T11	1748 (141)	2041 (285)	294 [-14]	1019 (171)			728 [-42]
T12	1895 (149)	2601 (559)	706 [-27]	1092 (153)			803 [-42]
L1	2212 (318)	2723 (428)	511 [-19]	1310 (192)			902 [-41]
L2	2512 (374)	2833 (456)	321 [-11]	1507 (163)	1790 (310)	283 [-16]	1005 [-40]
L3	2708 (310)	2933 (382)	225 [-8]	1684 (216)	1850 (300)	166 [-9]	1024 [-38]
L4	2548 (305)	2234 (476)	314 [14]	1607 (202)	1730 (300)	123 [-7]	942 [-37]
L5	1534 (396)	986 (338)	548 [56]	1075 (440)			458 [-30]
S1	811 (213)			601 (143)			210 [-26]

[A] = Square mm

[B] = Male minus Female (Square mm)

Table 6. Trunk muscle cross sectional area and standard deviations () of the Right Rectus Abdomini. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Rectus Abdomini - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	461 (4)			397 (59)			64 [-14]
L1	576 (151)	576 (151)	0 [0]	474 (79)			103 [-18]
L2	624 (141)	712 (239)	88 [-12]	408 (105)	330 (160)	78 [24]	216 [-35]
L3	610 (133)	670 (133)	60 [-9]	410 (112)	370 (110)	40 [11]	200 [-33]
L4	621 (66)	750 (207)	129 [-17]	453 (101)	400 (100)	53 [13]	168 [-27]
L5	768 (64)	787 (250)	19 [-2]	511 (92)			257 [-33]
S1	775 (74)			555 (117)			220 [-28]

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 7. Trunk muscle cross sectional area and standard deviations () of the Left Rectus Abdomini. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Rectus Abdomini - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	515 (59)			448 (81)			66 [-13]
L1	608 (183)	514 (99)	94 [18]	485 (85)			123 [-20]
L2	663 (109)	748 (240)	85 [-11]	415 (91)	340 (120)	75 [22]	247 [-37]
L3	686 (112)	693 (177)	7 [0]	439 (124)	370 (120)	69 [19]	248 [-36]
L4	586 (106)	746 (181)	160 [-21]	451 (103)	410 (120)	41 [10]	136 [-23]
L5	771 (22)	802 (247)	31 [-4]	531 (99)			240 [-31]
S1	763 (73)			543 (102)			220 [-29]

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 8. Trunk muscle cross sectional area and standard deviations () of the Right External Oblique. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right External Oblique - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	832 (230)			492 (126)			341 [-41]
L1	913 (235)			577 (114)			336 [-37]
L2	937 (178)	1158 (222)	221 [-19]	657 (136)	370 (120)	287 [78]	280 [-30]
L3	1111 (215)	1276 (171)	165 [-13]	740 (119)	440 (140)	300 [68]	371 [-33]
L4	1042 (214)	915 (199)	127 [14]	726 (102)	460 (140)	266 [58]	316 [-30]
L5	702 (226)			638 (172)			64 [-9]
S1				483			

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 9. Trunk muscle cross sectional area and standard deviations () of the Left External Oblique. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left External Oblique - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	856 (123)			457 (71)			399 [-47]
L1	844 (219)			540 (102)			305 [-36]
L2	963 (248)	1351 (282)	388 [-29]	683 (149)	550 (160)	133 [24]	280 [-29]
L3	1190 (225)	1335 (213)	145 [-11]	715 (129)	600 (140)	115 [19]	475 [-40]
L4	1103 (200)	992 (278)	111 [11]	689 (102)	600 (160)	89 [15]	414 [-38]
L5	724 (278)			638 (135)			87 [-12]
S1				496			

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 10. Trunk muscle cross sectional area and standard deviations () of the Right Internal Oblique. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Internal Oblique - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12							
L1	325						
L2	428 (127)	1055 (173)	627 [-59]	337 (83)	400 (140)	63 [-16]	91 [-21]
L3	858 (308)	1515 (317)	657 [-43]	420 (140)	530 (130)	110 [-21]	438 [-51]
L4	892 (258)	903 (83)	11 [-1]	663 (107)	530 (180)	133 [25]	229 [-26]
L5	580 (150)			529 (182)			52 [-9]
S1				475			

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 11. Trunk muscle cross sectional area and standard deviations () of the Left Internal Oblique. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Internal Oblique - Cross-Sectional Area

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12							
L1	287						
L2	487 (146)	1027 (342)	540 [-53]	292 (61)	430 (150)	138 [-32]	195 [-40]
L3	845 (240)	1424 (310)	579 [-41]	374 (138)	580 (150)	206 [-35]	470 [-56]
L4	944 (114)	900 (115)	44 [5]	686 (97)	520 (150)	166 [32]	258 [-27]
L5	587 (243)			603 (193)			16 [3]
S1				586			

^{A} = Square mm
^{B} = Male minus Female (Square mm)

Table 12. Trunk muscle cross sectional area and standard deviations () of the Right Psoas. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Psoas - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		330 (210)					
L1	703	513 (329)	190 [37]	127			576 [-82]
L2	922 (215)	1177 (285)	255 [-22]	317 (102)	580 (150)	263 [-45]	605 [-66]
L3	1564 (131)	1594 (369)	30 [-2]	601 (178)	830 (190)	229 [-28]	964 [-62]
L4	1980 (203)	1861 (347)	119 [6]	907 (171)	980 (200)	73 [-7]	1073 [-54]
L5	1984 (270)	1606 (198)	378 [24]	981 (166)			1003 [-51]
S1	1633 (267)			975 (142)			657 [-40]

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 13. Trunk muscle cross sectional area and standard deviations () of the Left Psoas. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Psoas - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		462 (190)					
L1	703	488 (250)	215 [44]	198			505 [-72]
L2	997 (172)	1211 (298)	214 [-18]	357 (94)	590 (170)	233 [-39]	640 [-64]
L3	1578 (158)	1593 (291)	15 [0]	623 (153)	830 (190)	207 [-25]	955 [-61]
L4	1995 (102)	1820 (272)	175 [10]	933 (160)	980 (220)	47 [-5]	1063 [-53]
L5	1962 (273)	1590 (244)	372 [23]	1047 (180)			915 [-47]
S1	1662 (294)			963 (226)			699 [-42]

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 14. Trunk muscle cross sectional area and standard deviations () of the Right Quadratus Lumborum. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Quadratus Lumborum - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		320 (197)					
L1	279 (2)	392 (249)	113 [-29]	206 (35)			73 [-26]
L2	498 (54)	552 (192)	54 [-10]	208 (43)	300 (70)	92 [-31]	291 [-58]
L3	676 (105)	701 (212)	25 [-4]	237 (49)	410 (120)	173 [-42]	439 [-65]
L4	827 (33)	725 (209)	102 [14]	384 (51)	460 (100)	76 [-17]	443 [-54]
L5				452			
S1							

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 15. Trunk muscle cross sectional area and standard deviations () of the Left Quadratus Lumborum. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Quadratus Lumborum - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		326 (5)					
L1	300 (102)	404 (220)	104 [-26]	197 (26)			103 [-34]
L2	482 (101)	614 (189)	132 [-22]	200 (36)	330 (160)	130 [-40]	282 [-59]
L3	645 (113)	746 (167)	101 [-14]	274 (58)	450 (140)	176 [-39]	371 [-57]
L4	875 (101)	625 (249)	250 [40]	435 (51)	450 (130)	15 [-3]	440 [-50]
L5				501			
S1							

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 16. Vertebral body cross sectional area and standard deviations (). Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

SPINE - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	1037 (39)	798 (91)	239 [30]	700 (103)			337 [-32]
T9	1103 (46)	933 (112)	170 [18]	756 (89)			347 [-31]
T10	1092 (24)	1015 (125)	77 [8]	827 (85)			264 [-24]
T11	1208 (116)	1133 (124)	75 [7]	875 (84)			334 [-28]
T12	1225 (114)	1241 (166)	16 [-1]	908 (96)			317 [-26]
L1	1274 (140)	1334 (285)	60 [-5]	952 (100)			322 [-25]
L2	1367 (153)	1332 (294)	35 [3]	1006 (106)	1420 (240)	414 [-29]	361 [-26]
L3	1419 (204)	1415 (249)	4 [0]	1078 (125)	1520 (230)	442 [-29]	341 [-24]
L4	1378 (130)	1459 (270)	81 [-6]	1098 (135)	1530 (220)	432 [-28]	279 [-20]
L5	1538 (237)	1360 (276)	178 [13]	1152 (166)			386 [-25]
S1	1684 (269)			1349 (260)			334 [-20]

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 17. Trunk mass cross sectional area and standard deviations (). Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

TRUNK - Cross-Sectional Area

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	71650 (5942)	65794 (5254)	5856 [9]	45625 (3866)			26025 [-36]
T9	68529 (6433)	61732 (6960)	6797 [11]	44019 (3964)			24510 [-36]
T10	63638 (5577)	61051 (7570)	2587 [4]	41963 (3603)			21675 [-34]
T11	59904 (5532)	59249 (7272)	655 [1]	40567 (3740)			19337 [-32]
T12	56745 (5700)	63287 (9153)	6542 [-10]	40011 (3660)			16734 [-29]
L1	54044 (5204)	59091 (6899)	5047 [-9]	39209 (3807)			14835 [-27]
L2	50632 (4412)	55834 (8112)	5202 [-9]	37964 (3829)	44300 (12200	6336 [-14]	12668 [-25]
L3	49623 (4248)	54286 (8702)	4663 [-9]	36511 (4503)	50900 (16800	14389 [-28]	13112 [-26]
L4	49863 (5356)	51813 (9845)	1950 [-4]	37379 (4914)	57600 (15900	20221 [-35]	12485 [-25]
L5	50365 (5324)	52912 (9123)	2547 [-5]	45038 (5136)			5327 [-11]
S1	54888 (4485)			51202 (5722)			3686 [-7]

[A] = Square mm
[B] = Male minus Female (Square mm)

Table 18. Right Latissimus Dorsi muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Latissimus Dorsi - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	-18 (7)	-18 (9)	0 [-3]	-14 (8)			3 [-17]
T9	-19 (7)	-22 (7)	3 [-12]	-18 (7)			1 [-6]
T10	-23 (6)	-24 (7)	0 [-4]	-22 (6)			1 [-5]
T11	-27 (8)	-32 (7)	5 [-17]	-24 (5)			2 [-9]
T12	-31 (6)	-39 (8)	8 [-20]	-27 (7)			4 [-14]
L1	-36 (7)	-47 (10)	11 [-23]	-32 (8)			4 [-12]
L2	-39 (7)	-47 (12)	8 [-16]	-38 (9)	-36 (9)	2 [5]	1 [-4]
L3	-39 (3)	-45 (16)	6 [-13]	-17 (59)	-30 (10)	13 [-42]	22 [-56]
L4	-29				-17 (11)		
L5							
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 19. Left Latissimus Dorsi muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Latissimus Dorsi - Raw Sagittal Moment Arms

Level	OSU Male mean^A (s. d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8	-13 (6)	-17 (7)	4 [-23]	-13 (9)			979 [-43]
T9	-16 (7)	-19 (7)	4 [-18]	-16 (9)			866 [-45]
T10	-18 (5)	-23 (7)	5 [-21]	-20 (9)			747 [-46]
T11	-21 (3)	-28 (9)	7 [-25]	-24 (7)			639 [-46]
T12	-27 (4)	-37 (8)	10 [-28]	-27 (7)			508 [-44]
L1	-31 (5)	-46 (7)	15 [-33]	-29 (7)			469 [-50]
L2	-34 (4)	-46 (10)	12 [-26]	-37 (10)	-34 (11)	3 [8]	317 [-49]
L3	-35 (4)	-43 (17)	8 [-18]	-37 (8)	-30 (10)	7 [22]	197 [-56]
L4	-32				-14 (13)		
L5							
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 20. Right Erector Spinae muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Erector Spinae - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	-53 (2)	-52 (3)	1 [3]	-43 (2)			10 [-19]
T9	-54 (3)	-52 (4)	2 [4]	-44 (3)			10 [-19]
T10	-53 (3)	-54 (4)	0 [-1]	-43 (3)			10 [-19]
T11	-52 (3)	-54 (4)	2 [-4]	-43 (3)			9 [-17]
T12	-51 (3)	-56 (5)	5 [-9]	-43 (3)			8 [-16]
L1	-52 (3)	-59 (5)	7 [-12]	-46 (4)			6 [-12]
L2	-53 (4)	-61 (5)	8 [-12]	-49 (3)	-54 (4)	5 [-10]	5 [-9]
L3	-56 (4)	-61 (5)	5 [-7]	-51 (3)	-52 (4)	0 [-2]	5 [-10]
L4	-57 (4)	-61 (5)	4 [-6]	-51 (2)	-52 (3)	0 [-2]	6 [-11]
L5	-63 (4)	-64 (6)	1 [-2]	-55 (5)			8 [-13]
S1	-62 (5)			-56 (4)			6 [-10]

A = millimeters (mm)
B = Male minus Female (mm)

Table 21. Left Erector Spinae muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Erector Spinae - Raw Sagittal Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8	-51 (3)	-51 (3)	0 [0]	-42 (2)			9 [-17]
T9	-52 (4)	-51 (4)	1 [2]	-44 (2)			9 [-17]
T10	-51 (3)	-52 (4)	1 [-2]	-43 (2)			8 [-16]
T11	-49 (3)	-52 (4)	3 [-6]	-42 (3)			7 [-14]
T12	-50 (4)	-57 (5)	7 [-13]	-42 (3)			7 [-15]
L1	-51 (3)	-60 (4)	9 [-15]	-46 (3)			5 [-10]
L2	-53 (4)	-62 (5)	9 [-14]	-49 (3)	-54 (4)	5 [-9]	4 [-8]
L3	-56 (3)	-61 (5)	5 [-8]	-52 (3)	-53 (2)	1 [-2]	4 [-7]
L4	-57 (3)	-61 (5)	4 [-6]	-52 (2)	-54 (4)	2 [-4]	5 [-9]
L5	-62 (5)	-63 (5)	0 [0]	-56 (4)			7 [-11]
S1	-62 (4)			-56 (4)			5 [-9]

A = millimeters (mm)
B = Male minus Female (mm)

Table 22. Right Rectus Abdominis muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Rectus Abdominis - Raw Sagittal Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12	122 (8)			102 (9)			20 [-17]
L1	115 (6)	109 (8)	6 [5]	92 (11)			23 [-20]
L2	99 (6)	90 (14)	9 [10]	83 (11)	70 (15)	13 [19]	16 [-16]
L3	86 (7)	79 (13)	7 [9]	69 (10)	70 (19)	1 [-2]	17 [-20]
L4	79 (12)	73 (14)	6 [8]	60 (10)	69 (20)	9 [-13]	19 [-24]
L5	75 (13)	81 (16)	6 [-7]	62 (10)			13 [-18]
S1	87 (19)			72 (11)			15 [-17]

A = millimeters (mm)
B = Male minus Female (mm)

Table 23. Left Rectus Abdominis muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Rectus Abdominis - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	126 (5)			103 (10)			22 [-18]
L1	118 (5)	112 (6)	6 [5]	95 (13)			23 [-20]
L2	101 (4)	92 (14)	9 [10]	85 (12)	72 (16)	13 [19]	16 [-16]
L3	87 (5)	80 (14)	7 [9]	70 (11)	72 (19)	2 [-3]	17 [-20]
L4	79 (10)	73 (14)	6 [8]	60 (10)	70 (20)	10 [-14]	19 [-24]
L5	76 (11)	80 (15)	4 [-5]	61 (11)			15 [-19]
S1	87 (18)			71 (11)			17 [-19]

A = millimeters (mm)
B = Male minus Female (mm)

Table 24. Right External Oblique muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right External Oblique - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	73 (4)			72 (10)			0 [0]
L1	59 (11)			55 (15)			4 [-7]
L2	39 (14)	28 (12)	11 [40]	36 (10)	22 (13)	14 [64]	3 [-8]
L3	25 (6)	20 (14)	5 [25]	18 (11)	23 (12)	5 [-21]	7 [-27]
L4	28 (10)	35 (10)	7 [-20]	16 (7)	30 (13)	15 [-48]	12 [-44]
L5	46 (15)			31 (15)			15 [-33]
S1				60			

A = millimeters (mm)
B = Male minus Female (mm)

Table 25. Left External Oblique muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Data collected (OSU) are compared with literature values for males and females. (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left External Oblique - Raw Sagittal Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12	87 (0)			70 (12)			17 [-19]
L1	67 (5)			56 (12)			11 [-16]
L2	48 (10)	28 (11)	20 [70]	39 (11)	20 (11)	19 [93]	9 [-19]
L3	25 (4)	19 (11)	6 [33]	17 (10)	20 (11)	3 [-15]	8 [-33]
L4	27 (9)	32 (18)	5 [-17]	14 (10)	30 (12)	16 [-54]	13 [-49]
L5	42 (15)			29 (10)			13 [-31]
S1				53			

A = millimeters (mm)
B = Male minus Female (mm)

Table 26. Right Internal Oblique muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Internal Oblique - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12							
L1	79						
L2	63 (22)	36 (17)	27 [76]	57 (12)	24 (14)	33 [137]	7 [-10]
L3	36 (12)	25 (9)	11 [43]	34 (12)	21 (11)	13 [62]	2 [-5]
L4	29 (14)	41 (12)	12 [-30]	17 (8)	30 (15)	13 [-43]	12 [-40]
L5	48 (10)			36 (10)			11 [-23]
S1				58			

A = millimeters (mm)
B = Male minus Female (mm)

Table 27. Left Internal Oblique muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Internal Oblique - Raw Sagittal Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12							
L1	90						
L2	70 (10)	40 (16)	30 [75]	60 (17)	25 (16)	35 [141]	10 [-14]
L3	40 (11)	26 (12)	14 [53]	38 (11)	20 (10)	18 [91]	2 [-4]
L4	32 (9)	41 (17)	9 [-23]	18 (7)	28 (13)	10 [-37]	14 [-44]
L5	48 (13)			35 (12)			13 [-27]
S1				50			

A = millimeters (mm)
B = Male minus Female (mm)

Table 28. Right Psoas muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Psoas - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		-14 (2)					
L1	-9	-11 (6)	2 [-20]	-1			8 [-87]
L2	-5 (3)	-9 (5)	4 [-47]	-10 (3)	-11 (3)	1 [-11]	5 [103]
L3	-4 (4)	-7 (5)	3 [-43]	-11 (2)	-8 (4)	3 [31]	7 [164]
L4	-1 (1)	1 (5)	2 [-202]	-7 (3)	-2 (5)	5 [230]	6 [549]
L5	9 (5)	18 (9)	9 [-52]	2 (3)			7 [-76]
S1	24 (10)			17 (3)			7 [-28]

A = millimeters (mm)
B = Male minus Female (mm)

Table 29. Left Psoas muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Psoas - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		-11 (1)					
L1	-9	-11 (4)	2 [-14]	-2			7 [-76]
L2	-5 (5)	-8 (2)	3 [-40]	-9 (4)	-11 (4)	2 [-15]	4 [93]
L3	-3 (5)	-6 (4)	3 [-50]	-10 (2)	-8 (5)	2 [19]	7 [217]
L4	1 (3)	2 (4)	0 [-43]	-7 (3)	-2 (4)	5 [244]	8 [-707]
L5	10 (7)	19 (8)	9 [-49]	1 (2)			8 [-86]
S1	27 (10)			17 (4)			10 [-38]

A = millimeters (mm)
B = Male minus Female (mm)

Table 30. Right Quadratus Lumborum muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Quadratus Lumborum - Raw Sagittal Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12		-31 (6)					
L1	-30 (3)	-35 (4)	5 [-16]	-26 (2)			3 [-11]
L2	-30 (4)	-37 (6)	7 [-18]	-31 (4)	-36 (4)	5 [-14]	0 [2]
L3	-32 (3)	-37 (6)	5 [-14]	-34 (5)	-32 (7)	2 [7]	2 [7]
L4	-31 (4)	-36 (9)	5 [-14]	-31 (3)	-28 (7)	3 [11]	0 [0]
L5				-21			
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 31. Left Quadratus Lumborum muscle anterior-posterior moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent posterior of the vertebral centroid while positive values represent anterior of the vertebral centroid. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Quadratus Lumborum - Raw Sagittal Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		-31 (6)					
L1	-30 (3)	-35 (4)	5 [-16]	-26 (2)			3 [-11]
L2	-30 (4)	-37 (6)	7 [-18]	-31 (4)	-36 (4)	5 [-14]	0 [2]
L3	-32 (3)	-37 (6)	5 [-14]	-34 (5)	-32 (7)	2 [7]	2 [7]
L4	-31 (4)	-36 (9)	5 [-14]	-31 (3)	-28 (7)	3 [11]	0 [0]
L5				-21			
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 32. Right Latissimus Dorsi muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Latissimus Dorsi - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	-153 (13)	-145 (7)	8 [5]	-129 (8)			24 [-16]
T9	-144 (10)	-141 (8)	3 [2]	-122 (7)			23 [-16]
T10	-135 (10)	-140 (9)	5 [-4]	-111 (5)			23 [-17]
T11	-126 (8)	-129 (9)	3 [-2]	-107 (4)			19 [-15]
T12	-120 (6)	-129 (10)	9 [-7]	-102 (5)			18 [-15]
L1	-116 (5)	-122 (12)	6 [-5]	-99 (8)			17 [-14]
L2	-109 (5)	-108 (8)	0 [0]	-91 (10)	-100 (11)	9 [-9]	18 [-17]
L3	-104 (6)	-102 (8)	2 [2]	-101 (28)	-106 (16)	5 [-5]	3 [-3]
L4	-108				-119 (11)		
L5							
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 33. Left Latissimus Dorsi muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Latissimus Dorsi - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s. d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	150 (6)	143 (6)	7 [5]	129 (6)			20 [-14]
T9	141 (5)	139 (8)	2 [1]	122 (8)			19 [-14]
T10	132 (4)	137 (9)	5 [-3]	112 (7)			20 [-15]
T11	125 (7)	129 (10)	4 [-3]	107 (5)			19 [-15]
T12	119 (8)	128 (7)	9 [-7]	102 (4)			17 [-14]
L1	114 (6)	117 (11)	3 [-3]	101 (8)			13 [-11]
L2	108 (7)	107 (9)	1 [1]	91 (12)	99 (12)	8 [-8]	17 [-15]
L3	103 (5)	104 (15)	0 [0]	90 (9)	107 (14)	17 [-15]	13 [-13]
L4	103				118 (15)		
L5							
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 34. Right Erector Spinae muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Erector Spinae - Raw Lateral Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8	-32 (3)	-31 (7)	0 [2]	-25 (4)			6 [-20]
T9	-31 (3)	-32 (4)	0 [-2]	-26 (5)			5 [-17]
T10	-34 (2)	-34 (4)	0 [-1]	-28 (4)			5 [-16]
T11	-33 (1)	-34 (4)	0 [-2]	-30 (3)			3 [-10]
T12	-36 (5)	-42 (3)	6 [-15]	-31 (3)			5 [-15]
L1	-40 (4)	-44 (5)	4 [-9]	-33 (4)			7 [-17]
L2	-41 (3)	-42 (4)	0 [-2]	-35 (3)	-34 (4)	0 [2]	6 [-16]
L3	-39 (3)	-40 (4)	1 [-3]	-34 (3)	-34 (4)	0 [0]	5 [-13]
L4	-36 (2)	-34 (7)	2 [6]	-35 (3)	-35 (4)	0 [-1]	2 [-4]
L5	-27 (4)	-22 (6)	5 [23]	-30 (5)			3 [10]
S1	-18 (1)			-20 (3)			3 [15]

A = millimeters (mm)
B = Male minus Female (mm)

Table 35. Left Erector Spinae muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Erector Spinae - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8	32 (6)	33 (6)	0 [-2]	27 (4)			5 [-15]
T9	34 (5)	35 (4)	0 [-2]	29 (3)			5 [-15]
T10	37 (3)	36 (3)	1 [4]	32 (3)			5 [-14]
T11	36 (2)	40 (3)	4 [-10]	33 (3)			3 [-9]
T12	37 (0)	40 (4)	3 [-7]	33 (3)			4 [-11]
L1	39 (2)	41 (7)	2 [-4]	35 (3)			4 [-11]
L2	39 (1)	41 (6)	2 [-5]	34 (4)	33 (4)	0 [3]	5 [-12]
L3	38 (0)	38 (5)	0 [0]	33 (4)	34 (4)	0 [-2]	4 [-12]
L4	35 (2)	33 (6)	2 [5]	33 (4)	35 (4)	2 [-7]	2 [-5]
L5	29 (6)	21 (5)	8 [36]	26 (7)			3 [-10]
S1	21 (2)			18 (2)			3 [-12]

A = millimeters (mm)
B = Male minus Female (mm)

Table 36. Right Rectus Abdominis muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Rectus Abdominis - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12	-43 (2)			-28 (6)			15 [-36]
L1	-42 (8)	-37 (8)	5 [12]	-32 (8)			10 [-23]
L2	-44 (7)	-46 (8)	2 [-4]	-33 (6)	-44 (12)	11 [-25]	11 [-25]
L3	-44 (8)	-43 (7)	1 [3]	-35 (6)	-43 (11)	8 [-19]	10 [-22]
L4	-43 (5)	-38 (7)	5 [12]	-37 (7)	-42 (11)	5 [-13]	6 [-14]
L5	-39 (4)	-32 (5)	7 [22]	-37 (8)			3 [-6]
S1	-35 (3)			-30 (8)			4 [-13]

A = millimeters (mm)
B = Male minus Female (mm)

Table 37. Left Rectus Abdominis muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Rectus Abdominis - Raw Lateral Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Female mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12	31 (0)			33 (3)			2 [6]
L1	37 (4)	35 (17)	2 [5]	36 (5)			0 [-3]
L2	40 (5)	43 (7)	3 [-6]	34 (6)	42 (10)	8 [-18]	6 [-14]
L3	39 (4)	38 (8)	0 [2]	33 (9)	43 (12)	10 [-24]	6 [-16]
L4	36 (8)	36 (7)	0 [-1]	36 (6)	41 (11)	5 [-13]	0 [0]
L5	31 (4)	33 (5)	2 [-5]	34 (7)			3 [9]
S1	30 (4)			34 (5)			4 [13]

A = millimeters (mm)
B = Male minus Female (mm)

Table 38. Right External Oblique muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right External Oblique - Raw Lateral Moment Arms

Level	OSU Male mean^{A} (s.d.)^{A}	McGill et al.,( ) mean^{A} (s.d.)^{A}	Difference^{A} [% Diff.]	OSU Female mean^{A} (s.d.)^{A}	Chaffin et al.,( ) mean^{A} (s.d.)^{A}	Difference^{A} [% Diff.]	Male vs Female^{B} [% Diff.]
T8							
T9							
T10							
T11							
T12	-126 (6)			-103 (7)			24 [-19]
L1	-129 (14)			-106 (9)			23 [-18]
L2	-130 (12)	-140 (5)	10 [-7]	-106 (6)	-117 (15)	11 [-9]	24 [-18]
L3	-127 (6)	-130 (10)	3 [-3]	-105 (6)	-120 (16)	15 [-12]	21 [-17]
L4	-126 (4)	-125 (13)	1 [1]	-111 (7)	-121 (14)	10 [-8]	16 [-12]
L5	-120 (5)			-113 (4)			7 [-6]
S1				-102			

A = millimeters (mm)
B = Male minus Female (mm)

Table 39. Left External Oblique muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left External Oblique - Raw Lateral Moment Arms

Level	OSU Male mean^A (s.d.)^A	McGill et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	OSU Fe male mean^A (s.d.)^A	Chaffin et al.,( ) mean^A (s.d.)^A	Difference^A [% Diff.]	Male vs Female^B [% Diff.]
T8							
T9							
T10							
T11							
T12	115 (9)			110 (4)			6 [-5]
L1	124 (11)			108 (7)			16 [-13]
L2	123 (12)	133 (7)	10 [-8]	107 (8)	117 (14)	10 [-8]	16 [-13]
L3	119 (8)	125 (9)	6 [-5]	105 (9)	122 (16)	17 [-14]	14 [-12]
L4	118 (6)	120 (9)	2 [-1]	109 (8)	123 (20)	14 [-12]	10 [-8]
L5	119 (4)			116 (10)			3 [-2]
S1				110			

A = millimeters (mm)
B = Male minus Female (mm)

Table 40. Right Internal Oblique muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Internal Oblique - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12							
L1	-130						
L2	-106 (14)	-123 (9)	17 [-14]	-89 (14)	-109 (15)	20 [-18]	17 [-16]
L3	-114 (8)	-116 (8)	2 [-2]	-93 (10)	-113 (16)	20 [-18]	21 [-18]
L4	-114 (4)	-109 (11)	5 [4]	-100 (7)	-115 (20)	15 [-13]	14 [-12]
L5	-106 (3)			-103 (1)			2 [-2]
S1				-89			

A = millimeters (mm)
B = Male minus Female (mm)

Table 41. Left Internal Oblique muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Internal Oblique - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12							
L1	120						
L2	102 (8)	121 (11)	19 [-16]	93 (17)	109 (15)	16 [-14]	8 [-8]
L3	106 (9)	112 (8)	6 [-5]	91 (14)	114 (16)	23 [-20]	14 [-14]
L4	104 (6)	103 (9)	1 [1]	98 (8)	114 (20)	16 [-14]	6 [-6]
L5	101 (4)			104 (8)			3 [3]
S1				98			

A = millimeters (mm)
B = Male minus Female (mm)

Table 42. Right Psoas muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Psoas - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		-32 (3)					
L1	-32	-32 (3)	0 [0]	-21			11 [-35]
L2	-35 (2)	-39 (2)	4 [-9]	-26 (2)	-33 (4)	7 [-22]	10 [-27]
L3	-41 (2)	-44 (3)	3 [-6]	-32 (3)	-37 (4)	5 [-14]	9 [-23]
L4	-50 (4)	-50 (3)	0 [0]	-39 (3)	-44 (4)	5 [-12]	11 [-22]
L5	-56 (3)	-54 (4)	2 [4]	-46 (4)			10 [-18]
S1	-59 (4)			-49 (5)			10 [-16]

A = millimeters (mm)
B = Male minus Female (mm)

Table 43. Left Psoas muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Psoas - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		32 (2)					
L1	33	31 (3)	2 [5]	23			10 [-31]
L2	35 (2)	38 (3)	3 [-9]	27 (1)	32 (4)	5 [-17]	8 [-23]
L3	39 (3)	42 (3)	3 [-6]	31 (2)	38 (4)	7 [-19]	8 [-22]
L4	46 (4)	48 (4)	2 [-4]	37 (2)	43 (4)	6 [-14]	9 [-20]
L5	53 (4)	54 (5)	1 [-3]	44 (3)			9 [-17]
S1	58 (3)			51 (4)			7 [-12]

A = millimeters (mm)
B = Male minus Female (mm)

Table 44. Right Quadratus Lumborum muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Right Quadratus Lumborum - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		-46 (11)					
L1	-46 (10)	-46 (6)	0 [0]	-34 (2)			12 [-25]
L2	-57 (9)	-63 (5)	6 [-10]	-40 (4)	-56 (8)	16 [-29]	17 [-30]
L3	-68 (6)	-75 (6)	7 [-10]	-53 (5)	-65 (7)	12 [-19]	15 [-22]
L4	-78 (2)	-81 (5)	3 [-3]	-66 (4)	-74 (8)	8 [-10]	12 [-15]
L5				-75			
S1							

A = millimeters (mm)
B = Male minus Female (mm)

Table 45. Left Quadratus Lumborum muscle lateral moment arm distance from the center of the vertebral body to the area centriod of the muscle cross sectional area and standard deviation (). Negative values represent right lateral and positive represent left lateral. Data collected (OSU) are compared with literature values for males and females. Differences between literature values and the current data are described in terms of area and as a percent of the literature values []. Absolute and percent differences in muscle areas between male and female subjects are also described.

Left Quadratus Lumborum - Raw Lateral Moment Arms

Level	OSU Male mean[A] (s.d.)[A]	McGill et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	OSU Female mean[A] (s.d.)[A]	Chaffin et al.,( ) mean[A] (s.d.)[A]	Difference[A] [% Diff.]	Male vs Female[B] [% Diff.]
T8							
T9							
T10							
T11							
T12		47 (5)					
L1	46 (5)	50 (6)	4 [-8]	36 (3)			10 [-23]
L2	56 (6)	64 (5)	8 [-12]	41 (4)	55 (7)	14 [-25]	15 [-26]
L3	67 (6)	73 (4)	6 [-8]	53 (8)	65 (7)	12 [-18]	14 [-20]
L4	74 (3)	78 (12)	4 [-6]	64 (7)	75 (10)	11 [-14]	9 [-13]
L5				78			
S1							

A = millimeters (mm)
B = Male minus Female (mm)

DISCUSSION

The subject of this report is to describe the progress of the research for the first year of the program. To date, our efforts are ahead of schedule regarding the anthropometric quantification of the female musculoskeletal torso, i.e. part 1. Our efforts are in accordance with the proposed timeline for part 2 of the research, quantifying female torso muscle force-velocity and length-strength relations. However, we intend to focus our efforts on part 1 before completing part 2. This will permit improved results, model validity, and accuracy of the military MMH assessment of LBD risk for women.

The results of the MRI data agree as much as can be expected with published results. Chaffin et al (11) in a review of existing CT scan data is the only published measurement of female torso muscle cross-sectional areas. Their data represents elderly women who had required medical imaging for diagnosis of a variety of disabilities. The data represents the muscle cross-sectional areas in transverse planes passing through the vertebral discs at three levels, L1-L2, L2-L3, L3-L4. Our data represents the transverse plane cross-sectional areas of the muscles as they pass through transverse planes passing through the center of the vertebral bodies at 11 levels, T8 to S1. Furthermore, our data is representative of younger women, without a history of back-pain or disability that might cause the need for diagnostic imaging. Consequently, some differences between the Chaffin et al (11) data and our data are to be expected, as our data is more representative of military age women. None-the-less, as described in table 2 to 45, the between muscle and between level trends are supported by the data described in Chaffin et al (11).

Data representing male anthropometry has been collected to permit one to directly compare female data with male data without the need to extrapolate for study design differences. Tables 2 through 45 suggest our male database to date, generally agrees with a similar study by McGill et al (15). The magnitude differences are typically within 10%. However, some notable exceptions can be identified. These differences are explained by the scan plane transverse level. McGill et al (15) collected data through the vertebral discs, whereas our data represents musculskeletal geometries in a transverse plane through the vertebral bodies. When the data is reviewed in this light (Tables 2 through 45), the magnitude of the differences is actually much smaller than suggested by the raw calculations. For example, McGill et al (15) report the cross-sectional area of the right latissimus dorsi as 232 mm^2 at the level of the disc below L3 (L3 in table 2) and 429 mm^2 at the level of the disc above L3 (L2 in table 2). Results from our scans through the vertebral body at L3 is a value of 353 mm^2. The muscle area grows from a value of 232 mm^2 at the lower vertebral disc (15), to 353 mm^2 through the vertebral body (OSU data), to 429 mm^2 at the upper vertebral disc (15), just as one might expect. Hence, MRI images of male subjects has been collected for comparison as a baseline for the female data, and the baseline male data is in general agreement with previous research results.

It must be noted that the data provided in the tables document the un-normalized values of muscle cross-sectional area and distances from the center of the spine. Considering the average male is significantly taller, wider and thicker (AP) through the trunk, it should be expected that the male muscle areas and moment arm distances are also larger. However, once the data are normalized to the respective body sizes, these differences will be accounted for. Thus, after normalizing the data, one will be able to identify the relative differences. For example, the normalized data might possibly illustrate that the erector spinae mass is a greater fraction of the trunk cross-section in one gender versus the other. These relative differences are the factors that will result in the most significant gender related variability in LBD risk other than scaling for size.

The muscle lines of action will be computed from the muscle moment arm data. Each muscle has an associated three-dimensional location relative to the center of the lumbo-sacral vertebral junction. These 3-D values are described by the lateral moment arm (X), the AP moment arm (Y), and the scan elevation (Z). With the 3-D centroid data describing each muscle, a vector description can be computed to represent the force vector, or line of action of each muscle. These will be achieved for each of the 14 measured muscles once the complete data set has been compiled.

With the normalized anthropometric data and line of action results, it will be possible to develop an accurate biomechanical model the female torso, and compare it directly with the male torso. This will be achieved by integrating the geometric data into an existing EMG-assisted model of spinal load developed from measurements of male subjects at The Ohio State University. With the validated model it will be possible to assess the spinal loads and associated risk of LBD of women performing MMH tasks as part of their military MOSs.

PROBLEMS EXPERIENCED IN THIS REPORTING PERIOD

Using existing MRI images would suggest that the data represents the musculoskeletal geometries of individuals who may have suffered selective muscle atrophy due to their disabling limitations, or muscle insufficiency that may have ultimately caused the disability or injury. Furthermore, most existing torso images lack the range of view to completely evaluate the entire transverse plane of the trunk at levels S1 through T8. In order to generate a more realistic description of active military women, we took in upon ourselves to obtain alternative funding to scan healthy women instead of collecting data from existing MRI scans of disabled or injured women. The opportunity to obtain dedicated time on the MRI scanner allows more realistic representations of military women, and permits us to obtain images specific to the geometric needs of this study. This will result in improved biomechanical modeling and assessment of military MMH tasks performed by women.

We have identified a geometrical limitation that must be overcome regarding the centriod of the internal and external oblique muscles of the torso. When viewed on a transverse plane MRI scan, the oblique muscles of the trunk appear as crescent shaped images. Plane geometry can be used to demonstrate that the area centroid of a crescent shaped region may be located outside of the region. Specifically, a highly curved crescent shape will possess a area centroid in the concave region of the figure. Consequently, measured distances from the center of the spinal vertebra to the area centriod of the oblique muscles, which is used to describe the moment arm distances of those muscles, may be a lower estimate of the distance. We must therefore, generate a method to correct the moment arm data representing the obique muscles relative to the trunk width. However, review of the lateral moment arm data collected to date (Tables 32 through 45) demonstrate our values agree with those of McGill et al (15), indicating the correction will not require a large change in the existing data.

PART 2 : Physiologic measurement of the in-vivo muscular length-strength and force-velocity relationships in the female trunk torso

BACKGROUND AND OBJECTIVES

The objective of Part 2 was to generate descriptive statistics to describe the relative force-length and force-velocity relations that describe the dynamics muscle behavior of military age women. This is necessary to permit accurate biomechanical modeling of MMH tasks under dynamic conditions. Thus, in order to generate accurate assessments of spinal loading and associated LBD risk of females performing military MMH tasks, it is necessary to generate the physiologic description of muscle dynamics accurately describes military age women. To date there have been only two in vivo assessments of trunk muscle length-strength and force-velocity behavior applicable to the dynamic biomechanical modeling of lifting tasks (16, 17). Both of those previous analyses examined only male volunteers, and may not accurately represent the physiological behavior of military women. Hence, the goal of this part of the research is to quantify the force-length and force-velocity behaviors of military aged women.

ADMINISTRATIVE NOTE

The reserach of Part 2 includes equipment calibration and development of the methods described in the research proposal, data collection, and derivation of the force-length and force-velocity relations from the in vivo data. Accurate quantification of the muscle behavior, i.e. force-length and force-velocity relations, are critical for accurate biomechanical assessment of MMH exertions. Therefore, to improve quality of the data from which the muscle behaviors shall be derived, an accurate set of muscle anthropometric geometries must be incorporated into the anlyses. The improved anthropometric measurements obtained from the results of part 1 of this research will permit more accurate modeling of muscle length-strength and force-velocity relationships of female trunk muscles, which will in turn improve the accuracy of the modeled spinal loads. It is therefore logical that part two of the research, quantification of the force-velocity relationship and length-strength relationships in female subjects, be performed using the results of the MRI analyses.

Consequently, we are focusing our efforts on completing part 1, the MRI analyses, prior to continuing with part 2, the length-strength and force-velocity measurements.

To further improve the accuracy of the biomechanical assessments of military MMH tasks, eccentric muscle function must be described in order to represent the biomechanical behavior of muscles as they lengthen. This is critical in the description of lowering tasks wherein the primary force generating muscles of the trunk, and the most significant source of spinal load, is generated by the extensor muscles of the trunk as they lengthen. Hence, we have undertaken an effort to describe the eccentric behavior of the force-velocity relationship, and validate the force-length relationship under eccentric conditions. Considering the complete data set describing the musculoskeletal anthropometry of female subjects is still under development, it is logical to appraise the value of this effort using male subjects. Based upon the results we achieved from the study of male subjects, we have demonstrated that the experimental methods for describing female force-velocity physiology should be augmented to include eccentric evaluation.

Mr. Kermit Davis spearheaded the research effort to quantify eccentric force-velocity behavior and examine the influence of eccentric muscle contraction on the biomechanical model performance. The methods, and results are a synopses of his work (18).

METHODS

Experimental Task : Subjects were recruited to perform lifting and lowering exertions under isokinetic and isometric conditions. Concentric exertions were performed by lifting loads of 20 lb. (9.1 kg), 40 lb. (18.2 kg), and 60 lb. (27.3 kg) at constant angular velocities (isokinetic) of 5 deg/s, 10 deg/s, 20 deg/s, 40 deg/s and 80 deg/s, starting from a trunk flexion angle of 40^0 and finishing in an upright posture. Eccentric exertions were performed by lowering a weighted box with handles at constant angular velocities (isokinetic), starting from an upright posture and finishing at a trunk flexion angle of 40^0. Subjects controlled their trunk velocity by observing a video screen displaying their instantaneous trunk motions. They were required to maintain the motion display trace within the envelope which was constructed to guide them through a constant velocity of flexion or extension.

Independent variables included: 1) trunk moment amplitude, 2) trunk moment direction, 3) trunk position and 4) isokinetic velocity. **Dependent variables** included normalized EMG measured from surface electrodes over the right and left pairs of the erector spinae, latissimuss dorsi, posterior abdominal internal obliques, rectus abdomini and the abdominal external obliques (5,19). MVC exertions consisting of: sagittal extension and flexion, right and left lateral flexion, and right and left twisting exertions were performed to achieve data for EMG normalization.

Subjects : Ten male subjects aged 22 to 34 years with mean height (±STD) of 181.0 ±6.6 cm. and mean weight (±STD) of 79.3 ±12.6 kg. volunteered to participate. All subjects were healthy and had no history of low-back pain.

Apparatus : Trunk muscle activity, kinetics, and kinematics were measured during the exertions A ten channel EMG amplification system was employed to monitor the trunk muscle activities, The Lumbar Motion Monitor (LMM) (20) was used to track three-dimensional lumbar spine position, velocity and acceleration. A force plate and Sacral Location and Orientation Monitor (SLOM) were used to determine the external forces and moments on the lumbar spine during a lifting exertion. A more complete description of these apparatus is described in the proposal for research for this contract.

Analyses : Biomechanical analyses of the data were performed by comparing measured trunk moments with un-modulated predicted levels. Predicted levels were achieved by implementing the EMG-assisted model without force-length and force-velocity modulation factors. Comparing measured and predicted isometric trunk moments as a function of muscle length represents the variation due to the physiological force-length relation. Similar analyses describe the force-velocity relation from isokinetic exertions. This method differs significantly from previous in-vivo or in-vitro analyses of muscle parameters (21,22,23,24) in that it includes the influences of muscle coactivity.

Independent, multi-dimensional trunk exertions will provide enough degrees of freedom to generate a fundamental representation of force-length and force-velocity relations for functional muscle groups of the female torso.

RESULTS

The existing length-strength modulation used in the Ohio State University EMG-assisted model (25,26,27) were developed to represent lifting (concentric) exertions. The current research has expanded those relationships to include eccentric muscle function. Muscle lengths were scaled to the rest muscle lengths, thus a length of 1.0 represents the muscle rest length. In the region between muscle lengths of 0.85 and 1.1, the original and revised relationships are almost identical. The original length-strength modulation remains a good estimate of the length-strength relationship for both eccentric and concentric lifting, correlation with the revised relation at R^2=0.975 to 0.995. Clearly, the muscle length-strength physiology of muscles is identical whether the contractile velocity is concentric or eccentric.

The equation of the original force-velocity modulation was given by equation 1

$$f(V) = 0.40*e^{-2.63*V} + 0.76 \tag{1}$$

where V is the instantaneous muscle contraction (eccentric or concentric) velocity. The relation developed from the recent data for concentric, i.e. lifting exertion (equation 2).

$$f(V) = 1.10*e^{-0.460*V} \tag{2}$$

The relationships describing the force-velocity modulation of the original data and the data for the recent concentric lifts were in close agreement throughout the range of typical concentric muscle velocities (0 to 0.9 rest lengths/s), with a correlation value of R^2=0.971. Therefore, the original force-velocity modulation curve remains a good estimate for the concentric lifts.

For the eccentric lifts, the "best fit" curve was a horizontal line (equation 3), therefore, the R^2

$$f(V) = 1.56 \tag{3}$$

can not be computed. The original force-velocity modulation for eccentric lifting was also a straight line that had a torque ratio equal to 2.0. In order to have mathematically continuous curvinilear response, a linear approximation was used to link the eccentric line to the concentric curve. The straight line approximation was used for the muscle velocities between -0.05 deg/s and 0.05 deg/s (equation 4).

$$f(V) = -4.6*V+1.33 \tag{4}$$

To determine the validity of the length-strength modulation and revised force-velocity modulation, the EMG-assisted model was exercised for both the eccentric and concentric lifts. Table 46 illustrates that the gains between the two types of lifts were almost identical. Similarly, the correlation (R^2) between the measured and model predicted trunk moments were actually better for the eccentric lifts than the concentric lifts, 0.95 and 0.88 respectively. Additionally, the eccentric lifts had a lower average absolute error (AAE) than the concentric lifts. Thus the model performance is as good or better during lowering tasks as in lifting tasks with the revised force-velocity modulation factors.

Table 46. The model outputs for the eccentric and concentric lifts

Model Output	**Eccentric Lifts**		**Concentric Lifts**	
	Mean	**STD**	**Mean**	**STD**
Gain	46.95	22.93	45.00	19.93
R-Squared	0.95 ^{A}	0.09	0.88 ^{B}	0.19
Avg Absolute Error	7.75 ^{A}	4.74	9.28 ^{B}	6.36

* Different alpha characters indicate a significant difference at $p \leq 0.05$.

The model performance with the revised force-velocity modulation factors was further validated using an independent data set (28). The data set was obtained from conditions at various speeds and weights. The lifts required that the subjects started in a bent over position (approximately 40 degrees of flexion), lifted to the upright position, paused for a second and then lowered to the bent over position. A total of twenty-two different lifts were analyzed, two lifts per subject. A summary of the basic model outputs can be found in Table 47

Table 47. Basic model outputs of lifting exertions from an independent data set (28) using the new modulation factors.

Model Output	Mean	Standard Deviation
Gain	41.8	12.02
R-Squared	0.91	0.05
Average Absolute Error	10.68	4.39
Percent of Maximum Mx	7.23	2.22

The performance of the model during a task with both eccentric and concentric components was suitable. The gain values were well within the physiological limits with a low standard deviation between the subjects. An average R^2 of 0.91 indicated that the internal moments fitted to the external moments accurately. The average absolute error averaged about 7% of the maximum measured trunk moment. Thus, the revised velocity modulations improve the performance and validity of the EMG-assisted model and its ability to predict spinal loading that occurs during MMH tasks.

DISCUSSION

The improved anthropometric measurements obtained from the results of part 1 of this research will permit more accurate modeling of muscle length-strength and force-velocity relationships of female trunk muscles, which will in turn improve the accuracy of the modeled spinal loads. It is therefore logical that part two of the research, quantification of the force-velocity relationship and length-strength relationships in female subjects, be performed using the results of the MRI analyses. Consequently, we are focusing our efforts on completing part 1, the MRI analyses, prior to continuing with part 2, the length-strength and force-velocity measurements.

The equipment calibration and method used to determine the force-velocity relationship and length-strength relationships has been tested using male subjects in accordance with the research proposal and timeline. Furthermore, the nature of the force-velocity relation has been improved through this research to allow description of eccentric as well as concentric muscle performance (18).

The results of the length-strength calibration and experiment demonstrate two items of interest. First, the methods applied under more constrained conditions are equally applicable to calibration of free-standing exertions. Second, the length-strength modulation factor describing muscle physiological behavior is independent of the direction of the exertion, i.e. lifting or lowering. The second fact is of use to the development of an assessment tool for the evaluation of military MMH activities. Velocity independence of the length-strength permits reduced complexity in the model as well as improved generality when interpreting results. The first item demonstrated that the length-strength modulation factors for female subjects can be developed that accurately represent free-standing lifting exertions, despite the motion constraints imposed during collection of the calibration data. Thus, the length-strength results give reason to believe the biomechanical model output when it has been developed to the point that evaluations of military MOS tasks involving MMH are performed.

The results of the force-velocity calibration experiment has demonstrated that an eccentric component must be included in the model for accurate representation of the biomechanics of MMH tasks. Thus, the proposed experimental methods will be expanded to determine both concentric and eccentric relations for the female subjects. As a result, the performance and validity of the spinal loads predicted from the evaluations of military task will be improved.

CONCLUSIONS

The goal of this research is to extend the capability of predicting musculoskeletal loads to women performing realistic MMH tasks. This tool will permit the assessment of risk associated with spinal loads during specific MMH tasks performed as part of MOSs that have recently been made available to military women. In this manner it will be possible to: a) assess spinal loads and associated risk for a given task, b) evaluate the physical attributes of a potential recruit that would place her at an increased risk of LBD, and c) determine how training or workplace procedures might be changed to minimize risk of LBDs to women (and men) performing the military MMH task.

We have concentrated on the first two parts of this research for the past year. These including 1) quantitatively describe the biomechanical geometry of the female trunk musculoskeletal system using Magnetic Resonance Imaging (MRI) technologies, and 2) determine the force-velocity relationship and length-strength relationships that are unique to the female trunk musculature.

Our efforts in these two parts of the research is progressing in accordance with the proposed timeline and as we expected. To date, we have collected a majority of the imaging data on the healthy women, and have analyzed over half of it. We have managed to expand this phase of the research, to allow assessment of healthy subjects and to collect data of healthy males for direct comparison. The results agree with the existing literature, indicating the methods, data, and processing we have been using will lead to valid conclusions. The equipment and methods to be for the determination of the force-length and force-velocity relationships have been calibrated and tested on a male population. Furthermore, the methods and associated validity of the results have been expanded to include representations of eccentric muscle contractions. Once a complete data set is achieved from the MRI study, we are confident the description of the force-length and force-velocity relationships will continue without difficulty.

We do not anticipate any changes will be necessary in the proposed research design. We have managed to improve the design in both parts one and two of the research without significant loss in time or effort. Given the manner in which this research interacts with other programs within our laboratory, developments in other efforts will continue to enhance the methods and validity of this effort.

In summary:

- Data collected in the first year of this effort look reasonable.

- Methods have been improved to enhance the research validity.

- Research efforts are moving forward as expected.

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DEPARTMENT OF THE ARMY
US ARMY MEDICAL RESEARCH AND MATERIEL COMMAND
504 SCOTT STREET
FORT DETRICK, MARYLAND 21702-5012

REPLY TO
ATTENTION OF:

MCMR-RMI-S (70-1y) 21 JUN 2001

MEMORANDUM FOR Administrator, Defense Technical Information Center (DTIC-OCA), 8725 John J. Kingman Road, Fort Belvoir, VA 22060-6218

SUBJECT: Request Change in Distribution Statement

1. The U.S. Army Medical Research and Materiel Command has reexamined the need for the limitation assigned to technical reports. Request the limited distribution statement for reports on the enclosed list be changed to "Approved for public release; distribution unlimited." These reports should be released to the National Technical Information Service.

2. Point of contact for this request is Ms. Judy Pawlus at DSN 343-7322 or by e-mail at judy.pawlus@det.amedd.army.mil.

FOR THE COMMANDER:

Encl

PHYLLIS M. RINEHART
Deputy Chief of Staff for
Information Management

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